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Chemical and microbiological aspects of the nitrogen cycle on marion island (sub-antarctic)

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Document Version
Publisher's PDF, also known as Version of record

Publication date:
1979

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Lindeboom, H. J. (1979). *Chemical and microbiological aspects of the nitrogen cycle on marion island (sub-antarctic).* s.n.

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S U M M A R Y

Marion Island ($46^{o}53'$ S, $37^{o}45'$ E), an extinct shield volcano, is situated in the Sub-Antarctic region of the Southern Indian Ocean. Its surface area of 290 km^2, consists of a coastal plain and a mountainous interior with the summit peak reaching to 1230 metres. The weather is characterised by low temperatures, heavy precipitation, and strong, predominantly westerly winds.

The flora consists of only 38 species of vascular plants. Like the flora, the fauna is characterised by a paucity of species. In terms of total numbers of animals, however, the island is very rich. Large rookeries of King Penguins and Macaroni Penguins are located on the east and north coast. Large number of Albatrosses and Petrels breed in the interior.

During the periods December 1975 - May 1976, November 1976 - December 1977, as well as April - May 1978, the chemical and microbiological aspects of the nitrogen cycle on Marion Island were studied. The purpose of this investigation was primarily to gain a survey of the importance of microorganisms in the nitrogen cycle as it occurs in different places on the island. In addition to this, many chemical determinations were performed to enable a model of this nitrogen cycle to be drawn up.

Nitrogen and phosphorus appeared to be important growth-limiting factors for bacteria, algae and plants (Chapter II). In places where no animals defecate, these two nutrients were not or hardly detectable and the number of microorganisms was relatively low ($< 10^6$ bacteria per ml water). In areas where birds and Elephant Seals defecate, nitrogen and phosphorus are introduced. These spots are recognizable by high numbers of bacteria (10^6 - 10^9 bact/ml) and a thriving vegetation.

All 120 strains of bacteria, isolated from altitudes below 500 m appeared to be psychrotrophic. Their optimum temperature was $28^{o}C$, and all of them were capable of growing at $0^{o}C$. Psychrophylic bacteria having a maximum growth temperature of less than $20^{o}C$ occurred only at higher altitudes (1000 m).

Nitrogen indispensable for the growth of bacteria and plants is introduced into Marion Island in different ways. Cyanobacteria, capable of fixing molecular nitrogen, are found mainly in algal

mats and in associations with mosses. With the acetylene-reduction method the nitrogen-fixing activity of algal mats was determined (Chapter III). The total amount of nitrogen introduced by fixation was estimated at 150-200 kg. Compared to other nitrogen sources, e.g. bird excreta, this amount is very small.

The most important nitrogen sources for the Marion Island ecosystem are the excreta of birds which forage at sea. 500-700 Tonnes of nitrogen are annually deposited on the island; most of it is deposited on the bare rocks in the penguin rookeries (Chapter IV). 80% of the nitrogen excreted by penguins during their moult fast appeared to be uric acid nitrogen with the remaining 20% being mainly proteins and ammonia. Since no uric acid was determined in the rookery deposit, it seemed to be reasonable to assume that all uric acid excreted by the penguins was rapidly decomposed. Chapter V describes some experiments to prove this rapid biodegradation. It appeared that this degradation proceeded fast at high temperatures ($20^{o}C$) and at high pH (> 7.0). At low temperatures ($6^{o}C$) the degradation rate decreased; but under both aerobic and anaerobic conditions the degradation rate was high enough to allow all uric acid produced by the penguins to be degraded. This degradation was performed both by microorganisms and by enzymes (released by the lysis of cells of bacteria), such as uricase and urease, which proved to be present in the rookery deposit. All uric acid nitrogen is converted into ammonia nitrogen. Due to the wet climate and the consequent bacterial activity, no guano accumulation occurs on Marion Island. On comparison of the N/P ratio of penguin excreta and that of the rookery deposit, it appeared that large amounts of ammonia (80%) evaporated.

Chapter VI deals with models of the nitrogen cycles in a Macaroni Penguin rookery during the moult fast and in a King Penguin rookery during the moulting period and the beginning of the breeding season. In both rookeries the degradation of uric acid into ammonia and the subsequent evaporation of the latter are, quantitatively, the most important processes. Nitrification and denitrification are relatively unimportant.

Part of the evaporating ammonia (8 - 20%) is deposited on the island. At least 40 - 50 tonnes nitrogen enter the vegetated areas this way. So, the penguins are more important for the total nitrogen cycle than was thought before. From enumerations of microorganisms involved in the nitrogen cycle it appeared that large numbers of both aerobic and anaerobic bacteria (10^6 - 10^9 bact/ml) occur in the penguin rookeries.

30 - 40 Tonnes of nitrogen in proteins and uric acid is annually deposited on the vegetation by birds, such as penguins, albatrosses and petrels (see introduction Chapter IV). The organic nitrogen compounds are rapidly degraded into ammonia, a part of which is subsequently nitrified. Both ammonia and nitrate, which are gradually leached by the heavy rains, can be used by bacteria and plants. Chapter VII described how this resulted in an increase in the numbers of bacteria.

Elephant Seals annually deposit 10 - 15 tonnes nitrogen as faecal proteins and urea in the wallows which are formed when they move inland to moult (Chapter VIII). In these wallows, containing large numbers of bacteria, the organic nitrogen compounds were rapidly degraded into ammonia. As a result of the high pH, caused by the high ammonia content, about one third of the ammonia evaporated; a part of the latter (2 - 3 tonnes) was deposited on the island again.

From this investigation it can be concluded that the input of uric acid and, to a smaller extent, that of proteins (excreta, feathers) by birds are the most important nitrogen sources for Marion Island. Microorganisms convert these organic compounds into ammonia. This ammonia is direct or indirect through evaporation and subsequent deposition the nitrogen source for a luxurious growth of vegetation.

Everywhere on the island the result of this nitrogen input can be observed by the fact that places with a large input, such as round a penguin rookery or albatross nest, a good growing evergreen vegetation of plants such as *Poa cookii* prevails. Places where the plants are hardly influenced by animals are characterised by a brownish vegetation which dies off in winter. From enzyme determinations in plant extracts it appeared that the glutamate dehydrogenase activity in *Poa cookii* leaves decreases as the influence of animal excreta on the plants increases.

The ammonia production in the rookeries of the Macaroni Penguins as well as the heavy rains and the predominantly westerly winds have produced an "ammonia shadow" around the rookery where a vigorous plant growth occurs. Since the herbivores are of no importance on the island and bacteria do not fully degrade the dead plants, a thick peat later has been formed around the penguin rookery. C^{14}-dating of this peat layer has shown that the Macaroni Penguins first bred on this place about 7000 years ago.

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